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Attentional shifts between surfaces: effects on detection and early brain potentials

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Abstract

Two consecutive events transforming the same illusory surface in transparent motion (brief changes in direction) can be discriminated with ease, but a prolonged interference (~ 500 ms) on the discrimination of the second event arises when different surfaces are concerned [Valdes-Sosa, M., Cobo, A., & Pinilla, T. (2000). Attention to object files defined by transparent motion. *Journal of Experimental Psychology: Human Perception and Performance*, *26*(2), 488–505]. Here we further characterise this phenomenon and compare it to the attentional blink AB [Shapiro, K.L., Raymond, J.E., & Arnell, K.M. (1994). Attention to visual pattern information produces the attentional blink in RSVP. *Journal of Experimental Psychology: Human Perception and Performance*, *20*, 357–371]. Similar to the AB, reduced sensitivity (d') was found in the two-surface condition. However, the two-surface cost was associated with a reduced N1 brain response in contrast to reports for AB [Vogel, E.K., Luck, S.J., & Shapiro, K. (1998). Electrophysiological evidence for a postperceptual locus of suppression during the attentional blink. *Journal of Experimental Psychology: Human Perception and Performance*, *24*(6), 1656–1674]. The results from this study indicate that the two-surface cost corresponds to competitive effects in early vision. Reasons for the discrepancy with the AB study are considered.

Keywords: Attention; Early vision; ERPs; Signal detection theory; Surfaces; Attentional blink

1. Introduction

Depending on the task, attentional selection can take place at different stages of processing. Lavie (1995) has proposed that selection operates at early stages only under conditions of high perceptual load. As argued recently by Luck and Hillyard (1999), the locus of attention depends on different processing stresses that determine in which cognitive subsystems selection is operating. The use of different experimental paradigms may therefore evince distinct types of attentional selection.

It has been firmly established (Hillyard & Münte, 1984; Mangun & Hillyard, 1988) that visuo-spatial attention (i.e. attending to certain locations) is reflected in a modulation of very early event-related potentials (ERPs). The P1 and N1 components elicited by stimuli flashed at attended locations are enhanced relative to the same components elicited by stimuli placed at unattended locations. Most of the relevant experiments have been performed with attention sustained at one location for long periods of time, and with a high stimulus load (fast presentation rates).

Not infrequently we must shift attention within a natural scene from one location to another, or from one object to another, under conditions that vary in perceptual load. These situations cannot be simulated by the classical sustained attention paradigm. More recently, other experimental designs in which attention shifts from trial to trial (and even within trials) have been employed. Several ERP studies (Mangun & Hillyard, 1991; Eimer, 1993, 1994a,b; Luck et al., 1994) have used the spatial cueing paradigm developed by Posner (1980). They have found that stimuli at validly cued locations are associated with a larger P1 and N1, than is the case for stimuli at invalidly cued locations. However if the subject is asked to respond to all stimuli (valid or invalid) the modulation is smaller (Eimer, 1994b).

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Another paradigm used to study selective visual attention is rapid serial visual presentation (RSVP), wherein streams of stimuli are flashed briefly at the same location. Several studies (Duncan, Ward, & Shapiro, 1994; Shapiro, Raymond, & Arnell, 1994; Ward, Duncan, & Shapiro, 1996) show that in RSVP recognition of one target (T1) produces a protracted interference in processing a subsequently presented target (T2). This phenomenon has been dubbed the 'attentional blink' (AB), in analogy with the brief interruption of information uptake during eye blinks. The AB results in failures of both discrimination and detection of the T2. A recent study by Vogel, Luck, and Shapiro (1998) reports that the attentional blink is not associated with a suppression of P1 and N1, in contrast with experiments using spatial cueing (and sustained attention with fast stimulus rates). This suggests that selection in the AB corresponds to relatively late stages of processing. Therefore when attention shifts within a trial, the early ERPs may or may not be modulated according to the nature of the task demands.

After a long controversy (Duncan, 1984), agreement has been reached that visual attention can select either locations or objects (Luck, Woodman, & Vogel, 2000). A recent study has shown that attention can be selectively directed towards one of two overlapped imaginary surfaces induced by transparent motion (Valdés-Sosa, Cobo, & Pinilla, 1998). Note that the surfaces occupied the same region of space thus precluding spatial selection. In a subsequent study, imaginary surfaces were induced by rotating differently colored dots in opposite directions. Fast and long trains of brief changes in motion direction affected the two surfaces. Sustained attention to events on one surface produced a substantial suppression of the early P1 and N1 elicited by events on the other (unattended) surface (Valdes-Sosa, Bobes, Rodriguez, & Pinilla, 1998). Therefore sustained selective attention to surfaces appeared to affect processing at an early stage, in the same way as described for sustained spatial attention.

We have recently developed a paradigm to study shifts of attention between the surfaces defined by transparent motion (Valdes-Sosa, Cobo, & Pinilla, 2000). The task consisted of discriminating within each trial only two successive events of the type described above (brief changes in motion direction). The discrimination was accurate for both of the events when they affected the same surface independently of inter-event delays. In contrast, at short inter-event delays (below 600 ms) the discrimination of the second event (or T2) was poor if it affected a surface different from the first (T1). This two-surface cost seems to reflect a difficulty in switching attention rapidly between surfaces, and occurred despite the spatial superposition of the two surfaces. We will call this phenomenon surface dwell-time (SurfDT).

SurfDT and the AB have interesting similarities. The paradigm eliciting SurfDT is formally similar to that eliciting the AB, especially the 'minimal' RSVP variant which does not use distracters (Duncan et al., 1994; Egeth & Yantis, 1997). In both phenomena, recognition of T1 hampers processing of a subsequently presented T2. The duration of the AB and SurfDT is also similar. However, we do not know if the processing constraints revealed by the two phenomena are the same or different and further comparisons are warranted.

In the present study we compare the AB and SurfDT in two respects. The AB produces both detection and discrimination deficits on T2 when T1 is attended. To extend previous work establishing discrimination deficits during the SurfDT, here the detection of events on the unattended surface was studied with a signal detection paradigm. Moreover, the effects of SurfDT on ERPs were also studied, to determine if P1 and N1 are modulated when attention shifts between surfaces thus revealing early attentional selection, or if these components are unaffected (as reported for the AB) indicating that late selection is involved.

2. Experiment 1

The problem of whether attention affects the quality or strength of sensory signals has been addressed before with detection paradigms in the context of the debate between 'early' and 'late' spatial-attentional selection. Bashinski & Bacharach (1980) were the first to report a reduction of d' for the detection of faint luminance changes at uncued locations, a finding that has been replicated in other studies (e.g. Reinitz, 1990).

One problem with the initial attempts to apply signal detection theory in spatial cueing paradigms (discussed in Downing, 1988 and Luck et al., 1994) was the ambiguity in assigning false alarms to either the cued or the uncued location. To solve this problem, post-cue signals have been used, to query for detection at specific locations on each trial. Significant effects of cue validity on d' have also been found applying this approach (Downing, 1988; Hawkins et al., 1990; Müeller & Humphreys, 1991; Luck et al., 1994).

The goal of this experiment was to examine if attention to one transparent surface reduced the capability to detect motion in another surface, in addition to the discrimination costs already described in previous articles. The paradigm was the same used in previous reports of SurfDT (Valdes-Sosa et al., 2000), with the exception that a 'yes/no' motion-detection response was required for the second event-motion in place of the discrimination task. The experiment was performed twice. In the first replication, false alarms were not assigned to a particular surface. In the second replication the post-cue design described above was adapted in order to assign false alarms to one of the two surfaces.

Table 1
Characteristics of the participants by experiment

Experiment	Age range	Sex		Handedness	
		Females	Males	Right	Left
1A	21–28	3	4	7	0
1B	21–29	9	1	9	1
2	24–43	1	9	9	1
3	24–30	2	3	5	0

2.1. Method

2.1.1. Participants

Personnel from the Cuban Center for Neuroscience, all university graduates, participated in the experiments reported in this article. Their age range, sex distribution, and handedness are described in Table 1. All the subjects had normal or corrected-to-normal visual acuity, reported no color vision abnormalities, and had no history of neurological disorders.

2.1.2. Stimulus material

Visual stimuli were presented on a sVGA monitor with a black background. A small circle of 28 arcmin diameter was placed at the center of the screen as a fixation point. The stimuli consisted of two interspersed sets of moving dots (100 dots each). The dots were one pixel in size and initially drawn at randomly selected locations within an imaginary circle (diameter of about 6.9°) centered on the fixation point. Each set moved in a different direction (Fig. 1). Heterochromatic flicker photometry was used for each participant, to obtain a green that was equiluminant with the maximum intensity of red. Each set of dots was assigned one of the two colors thus defined.

Two types of motion were used: baseline and event motion. In Fig. 1 the structure of the different types of trials is described. The baseline motion consisted of rigid rotation around the fixation point. The speed of rotation was about 40°/s of angular speed. Linear displacements in the cardinal and diagonal directions were used as events (eight alternatives), moving at a speed of

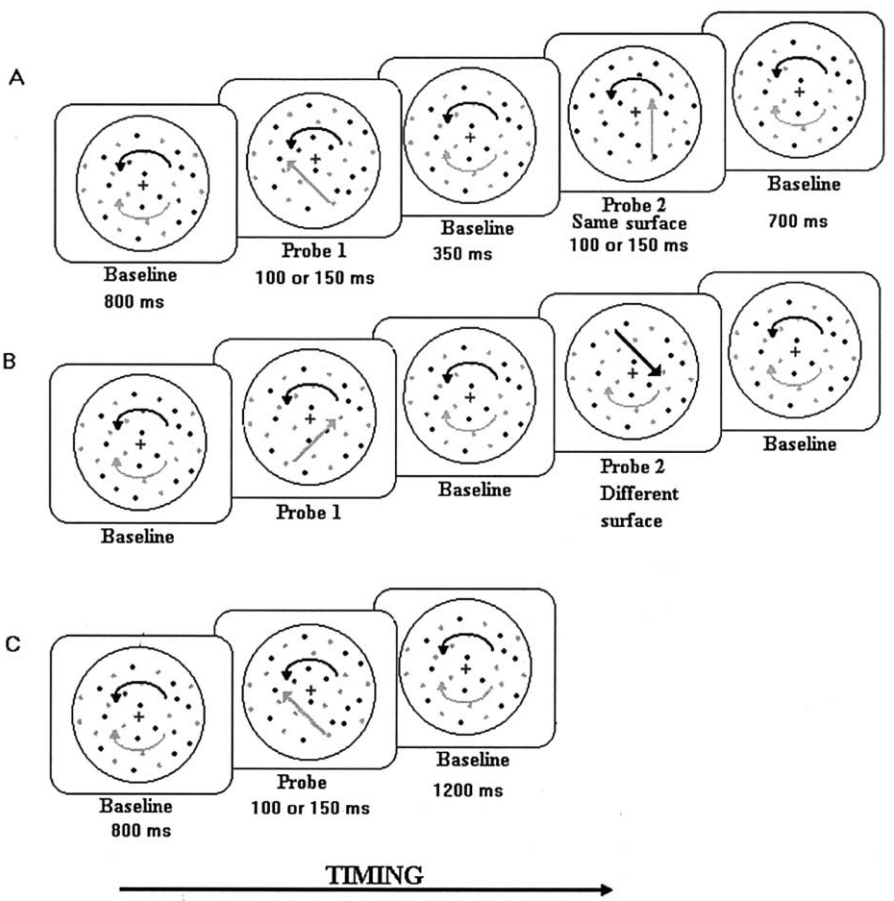

Fig. 1. Sequence of stimulus events in a trial. The background was actually black, and dots were either red or green isoluminant with the red (represented as black or gray). The color of the fixation point pre-cued the surface to be attended, where the first event would occurred. (A) Events in same-surface trials: both events affected the same pre-cued surface. (B) Events in different-surface trials: the second event affected the uncued surface, different from the one affected by the first pre-cued event. (C) Events in single-event trials: only the first event took place affecting the pre-cued surface. Note that event (and therefore SOA) duration was different in Experiments 1 and 2.

about 3°/s. The event motion was 60% coherent (see Valdes-Sosa et al., 2000 for a more detailed description).

2.1.3. Procedure and design

Participants initiated each trial by pressing the space bar of the computer keyboard. The color of the fixation circle forewarned which of the two surfaces was to be affected by the first event. Then stimulus motion began after a 500 ms delay, followed by an 800 ms baseline period in which the two sets of dots rotated in opposite directions (Fig. 1). Then an event lasting 150 ms affected the cued surface while the other surface continued to rotate. After this both surfaces rotated in the baseline pattern for 350 ms. Then a second 150 ms event was presented, followed by an additional 700 ms rotation period. The direction of the two events was always different.

The experiment was performed in one session, which consisted of 192 trials. The first event affected each set of dots on half the trials. On 96 of the trials, only the first event was presented in each trial. On the other 96 trials, two events were presented within each trial. The events affected the same surface in half of two-event trials, whereas different surfaces were involved on the other half. Thus, there were six possible combinations of events, two for the single-event trials (red–null, green–null), two for the same-surface trials (red–red, green–green), and two for the different-surface trials (red–green, and green–red).

At the end of the trial the participants were required to report the direction for the first event motion on the numerical-pad of the computer keyboard. They were then required to respond on one key if they had detected a second event-motion (and on another if they had not). In Experiment 1A, the participants were asked to respond 'yes' if they perceived any motion without reference to the surface on which it could have occurred. In Experiment 1B the query about the second motion was always referred to a specific set of dots (e.g. 'did the red dots move?'). In the case of two event-trials, the question was always asked of the surface on which the second event had affected (see Luck et al., 1994 for a similar design). When only one event was presented, on half of the trials the question was asked for the affected surface, and on the other half about the other surface.

The percentage of correct responses to the first event, as well as the Hits (saying 'yes' when a second event-motion had occurred) and False Alarms (saying 'yes' when the second event was absent), was obtained for each type of trial, in all participants. In Experiment 1B the false alarms were calculated separately for responses concerning the same surface on which the first event occurred, and for responses related to a different surface. Since the color of the dots did not produce any significant effect in subsequent analysis, data were also collapsed over this factor. The percentage of Hits and False Alarms was used to calculate the d' and logarithm of Beta (log-Beta) measures of Signal Detection Theory in each participant for the second event for each type of trial (Green & Swets 1966).

Table 2
Sensitivity for the detection of a second event in Experiment 1 for same-surface and different-surface trials[a]

	% Hits	% FA	d'	Log β
Experiment 1A				
Same	94 (6)	20 (14)	3.32 (1.4)	−1.4 (2.0)
Different	73 (25)	20 (14)	1.92 (1.1)	0.0 (1.2)
Experiment 1B				
Same	94 (5)	11 (7)	3.7 (1.3)	−0.8 (1.8)
Different	69 (26)	15 (9)	2.1 (1.5)	0.7 (2.0)

[a] Means and S.D. (the latter in parentheses) are indicated. Same and different rows refer to the surface on which the second event was placed in relation to the first event. In experiment 1A, there was only one common estimate of false alarms (FA) for the two conditions.

2.2. Results and discussion

Mean accuracy in discriminating the direction of the first event-motion was 84% (range across participants 73–92) in Experiment 1A and 90% (range 76–94) in Experiment 1B. The mean Hit rate was larger on same-surface trials than on different-surface trials (Table 2) in both experiments. These effects were significant, in both Experiment 1A, $t(6) = 2.7$, $P < 0.036$, and in Experiment 1B, $t(9) = 3.6$, $P < 0.006$.

In Experiment 1B where separate estimates were available the False Alarms were roughly equivalent for the two types of trial. In both experiments, the mean d' for same-surface trials was also larger than for different-surface trials, $t(6) = 5.16$, $P < 0.002$ for Experiment 1A and $t(9) = 3.6$, $P < 0.006$, for Experiment 1B. Despite the lower mean d' for the different-surface trials, in both experiments this value was significantly larger than zero ($P < 0.002$). The mean log-Beta scores in the same-surface trials were significantly more negative than in different-surface trials in both experiments, $t(6) = 3.5$, $P < 0.013$ and $t(9) = 2.6$, $P < 0.03$, for Experiments 1A and 1B, respectively.

More positive Log-Beta (or equivalently larger Beta) values were found in the different- compared to the same-surface trials. Similar effects on Beta have been reported in spatial cueing tasks (Müeller & Findlay, 1987; Downing, 1988; Luck et al., 1994; Müeller, 1994), with larger values for uncued compared to the cued locations. More conservative criterion would correspond to uncued locations because there is a low 'a priori' probability of targets being presented there (Müeller & Findlay, 1987; Müeller, 1994). In our case

the 'a priori' probability of presenting a target on the same or on a different surface as the first event was equal. However, if the participants 'missed' many of the events on the different-surface trials, this could lead to a low perceived relative-frequency for this type of event and therefore decisions that are more conservative. This idea is supported by a significant correlation across participants in Experiment 1B between d' and Log-Beta for the different-surface trials, $r = 0.76$, $t(9) = 3.3$, $P < 0.011$, but not for the same-surface trials.

The results from the two replications of the experiment are in complete agreement with each other. They indicate that when an event on one transparent surface captures attention, the detection of a rapidly following second event is hampered if it occurs on a different surface. This effect was measured by the d' measure which is free from the contamination of criterion variation (Green & Swets, 1966). Similar results have described in spatial cueing tasks, for the detection of luminance decrements (Bashinski & Bacharach, 1980), luminance increments (Downing, 1988; Hawkins et al., 1990; Müeller & Humphreys, 1991; Luck et al., 1994), as well as brightness, orientation, and form discriminations, (Downing, 1988). This extends previous findings (Valdes-Sosa et al., 2000) and shows that both discrimination and detection are affected when attention must switch from one surface to another at short notice.

3. Experiment 2

The previous study shows that SurfDT, like the AB, is associated with a deficit in detection and not only a difficulty in discrimination. In this experiment, we examine whether the early visual ERPs are affected during the SurfDT. If SurfDT behaves in a similar fashion as reported for the AB (Vogel et al., 1998), it should have little effect on these ERPs. With this aim in mind, the paradigm used in previous reports of SurfDT (Valdes-Sosa et al., 2000) was adapted for ERP recording. The onset of event motion was used as a trigger for the signal averaging used to estimate the ERPs. Several groups (Göpfert, Muller, & Simon, 1990; Kuba & Kubová, 1992a,b; Bach & Ullrich, 1994) have studied the ERPs elicited by motion-onset or changes in motion direction, in particular the first negative component, N1 (or N200). Recent experiments have shown that attention clearly modulates early components of the motion-onset ERPs, including N1 in other paradigms (Valdes-Sosa et al., 1998Torriente, Valdes-Sosa, Ramirez, & Bobes, 1999).

3.1. Method

The method was the same as in Experiment 1, except as described in the following. Participants were asked to report the direction of dominant (coherent) motion for both events described for Experiment 1. Event duration was restricted to 100 ms, thus the inter-event SOA was 450 ms.

The same three types of trial as in Experiment 1 were used: same-surface, different-surface, and single-event trials. Thus there were six possible combinations of events, two for the single-event trials (red–null, green–null), and two for the same-surface trials (red–red, green–green), and two for the different-surface trials (red–green, and green–red). For each of these conditions, 200 trials were presented in the whole session.

The procedure was identical to that of previous experiments (Valdes-Sosa et al., 2000). Additionally, the subjects were instructed to maintain fixation, and minimize body movements and eyeblinks during recording blocks. The session was divided into five blocks. The participants rested for a few minutes between blocks.

The percentage of correct responses to the first and second events was obtained for each type of trial, with data collapsed over blocks, in all participants. Since the color of the dots did not produce any significant effect in subsequent analysis, data were also collapsed over this factor. The percent correct scores were submitted to a rm-ANOVA with event-sequential-order (first vs. second) and number-of-surfaces (same-surface vs. different surface) as main effects.

3.2. Electrophysiological recording

Electrophysiological data acquisition and analysis were carried out on a MEDICID 3E (Neuronic SA) system. Disk electrodes (Ag/AgCl) were placed with electrolytic paste on eight active derivations (Pz, Oz, P3, P4, T5, T6, O1, and O2) of the 10/20 international system. All active electrodes were referred to linked earlobes. Inter-electrode impedance was always kept below 5 kOhm. Bipolar derivations were used to record the EOG, with electrodes just lateral to the external canthi for the horizontal movements and 1 cm above and below the right eye for the vertical movements. The signals were filtered between 0.05 and 70 Hz (3 dB down). Additionally, a notch filter with peak at the power line frequency was used. In each trial, marks corresponding to events (linear motion onset) were co-registered with the amplified and digitized EEG (12 bit resolution), which was sampled at a rate of 250 Hz, and stored on magnetic disk for off line analysis.

The continuous EEG record was windowed with a pre-stimulus baseline of 100 ms before pattern-onset, and a 700 ms post-stimulus epoch. Each EEG segment was visually inspected and trials with artifacts or excessive activity in the EOG were rejected. This eliminated from about 1 to 19% of all stimulus events across conditions, which resulted in individual ERPs based on

the average of about 162–198 events (collapsed over color in the following, since this factor was not significant in subsequent analysis). For every subject, averaged ERPs synchronized with event motion-onset were obtained for all recording sites, for each stimulus condition.

Since a short SOA was used in the two event trials, the ERPs elicited by the first event overlapped and distorted those related to the second event, which were the center of interest. The isolated responses related to the second event were estimated by subtracting in each individual the ERPs from the one-event trials (which contained only responses to the first event) from ERPs associated either to same-surface, or different surface trials. Grand average ERPs and difference waveforms were calculated for all groups of Ss for each site and condition. All data points were corrected (prior to plotting or measurement) by subtracting the average pre-stimulus amplitude value.

The attention effects were tested by two statistical procedures. The first, more traditional method was based on measuring the average amplitude of two time windows (corresponding to the P1 and N1 elicited by the second event). The measures were obtained from the difference waveforms at all sites; for each individual. The time windows were for P1 from 110 to 190 ms and for N1 from 240 to 330 ms. Separate rm-ANOVAs were performed for each component. Number-of-surfaces (same-surface vs. different-surface), electrode-site (temporal vs. occipital) and electrode-laterality (right vs. left), were the main effects in the ANOVA for P1 and N1. Number-of-surfaces and site (three levels) were the main effects in the ANOVA for P2. To examine scalp topography, an additional rm-ANOVA was performed for N1 with data from the eight active electrodes, with number-of-surfaces and electrode as main effects.

Recently, computer-intensive methods based on permutation principles have been proposed as an alternative statistical methodology for testing differences between ERPs (Blair & Karniski 1993; Blair & Karniski 1994; Galán et al., 1997). Non-parametric permutation techniques were used in the second statistical procedure. The global null hypothesis tested was the equality between the ERPs associated with same- and different-surface trials at all electrode derivations and for all time points. The marginal null hypothesis was the equality of the ERPs at each particular time points at any given electrode site. This procedure allows the location and timing of the effect to be located more precisely.

3.3. Results and discussion

3.3.1. Behavioral data

The accuracy in the direction judgment task is shown in Fig. 2. The first direction discrimination was very accurate for all conditions with no significant differences between the corresponding mean scores. The second discrimination was less accurate, although large decreases in performance were present only for the different-surface condition. The drop in accuracy from the first to the second discrimination was only about 10% when the events were on the same surface. The drop from the first to the second event was about 45% when they were placed on different surfaces.

These results were reflected in highly significant effects in a rm-ANOVA of event-sequential-order, $F(1,9) = 138.8$, $P < 0.00001$, and number-of-surfaces, $F(1,9) = 63.2$, $P < 0.00002$, as well as the interaction between the two factors, $F(1,9) = 109.0$, $P < 0.00001$. The interaction reflects that whereas the first discrimination was not affected by the number of surfaces involved, the judgment corresponding to the second event was significantly less accurate for the different-surface condition than for the same-surface condition, $F(1,9) = 92.3$, $P < 0.00001$.

The results indicate very little interference for judgments on the second event when it was placed on the same surface as the first event. In contrast, in the different-surface task case, where attention had to switch between surfaces, a large deterioration of perfor-

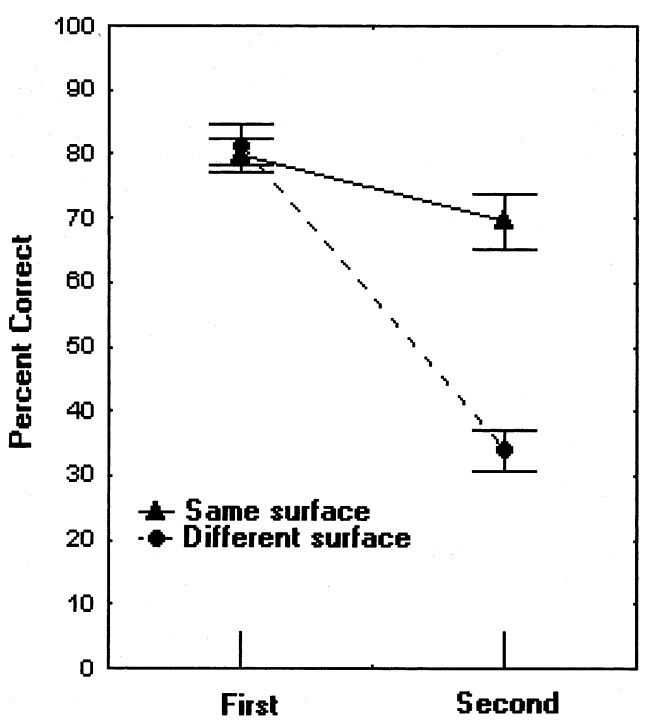

Fig. 2. Percent correct in Experiment 2 as a function of distribution of attention and event sequential order. The ordinate axis represents the sequential order in which the two events were presented. Each line represents a different type of trial. In the same-surface trials both events affected the same pre-cued surface. In the different surface trials the second event affected the uncued surface, which was different from the one affected by the first pre-cued event. Each data point corresponds to the mean of 10 subjects. The whiskers represent 1 S.E.

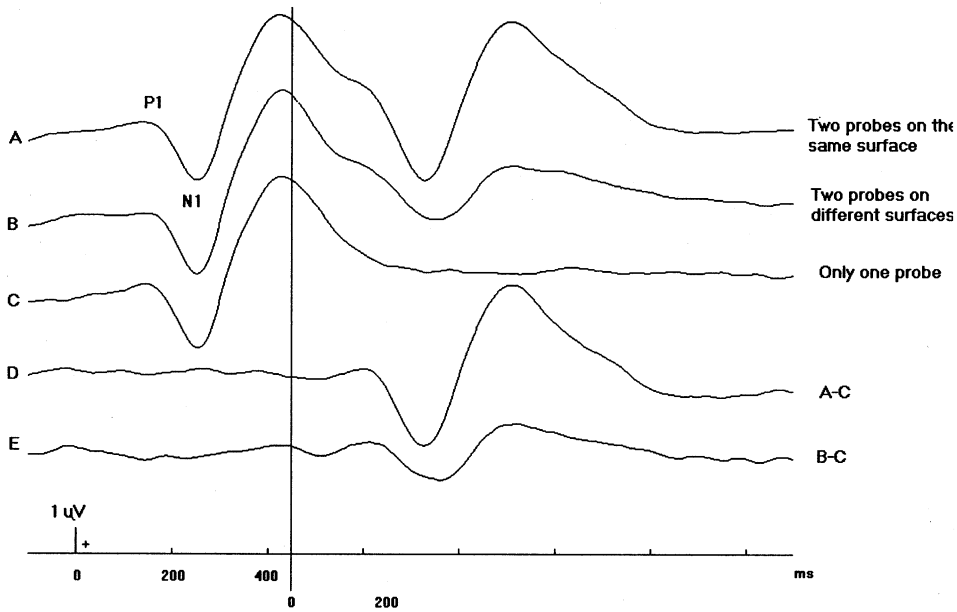

Fig. 3. ERPs obtained in Experiment 2. Grand averages of the ERPs elicited by event onset (for the 10 subjects) from right posterior temporal region (T6), for each type of trial: (A) Two events on the same surface; (B) Two events on different surfaces; (C) Only one event. The large vertical line corresponds to moment of the second event presentation. Ticks correspond to 200 ms marks. The P1 response is smeared with respect to the ERPs from individuals. The responses related to the second event were isolated by subtracting the ERPs from the one-event trials from ERPs associated either to same-surface (D), or different-surface trials (E). Positive points up.

mance for the second stimulus was obtained. These results replicate previous work (Valdes-Sosa et al., 2000), and strengthen the conclusion that under certain conditions there is a limit to the number of events from different objects that can be attended to within a short period of time.

3.3.2. ERP data

The grand average ERPs corresponding to the different conditions, used in the experiment, are displayed in Figs. 3 and 4A. Two sequential and distinct responses were observed in the original waveforms when the two events were presented. The response to the first event did not differ between conditions and will be ignored.

Several peaks (described in order of peak latency) were present in most participants in the difference waveform that isolated the response to the second event. These were P1, largest at occipital sites; N1, largest at posterior temporal sites and finally the P2 that was largest at Parietal sites and that will not be considered further. Information on the latency of these peaks is shown in Table 3. See Fig. 4B where the scalp distribution of N1 is presented in the same-surface condition.

There was no clear effect of the number-of-surfaces in the P1 time window. The only significant effect on P1 amplitude was that of electrode-laterality, $F(1,9) = 5.15$, $P < 0.05$, with amplitudes on the right side twice as large as on the left (0.2 vs. 0.4 μV). Therefore attentional effects were not found here for P1. However, before concluding that SurfDT does not affect P1 two aspects must be considered.

The P1 was very small in this study and dominated by the subsequent N1. Bach and Ullrich (1994) have demonstrated that when the motion duty-cycle (the amount of time that the relevant motion is present relative to when it is absent) is short, then N1 dominates the motion-onset ERP. Event duty-cycle here was short (if rotations and stationary conditions are lumped together). Furthermore, it is possible that the perceptual load in this study was insufficient. Psychophysical evidence suggests that attentional effects are earlier as the perceptual load is increased (reviewed in Lavie & Tsal, 1994). In a sustained attention experiment using stimuli similar to those used here, a higher perceptual load (faster event presentation rate), and a longer motion duty-cycle were used. A strong suppression of the P1 elicited by events on the unattended surface was found (Valdes-Sosa et al., 1998). Further research on this is necessary.

The N1 was substantially attenuated when it was on a different surface than the first event. This can be seen more clearly in the difference waveforms, where the contribution from the response to the second event is isolated (Figs. 3 and 4A). The rm-ANOVA confirmed this observation. In the rm-ANOVA for N1 amplitudes at posterior sites, the effect of number of surfaces was significant, $F(1,9) = 9.14$, $P < 0.014$, with a mean value of 1.9 μV for the same-surface condition and of 0.7 μV for the different-surface condition. Electrode-site and electrode-laterality were not significant.

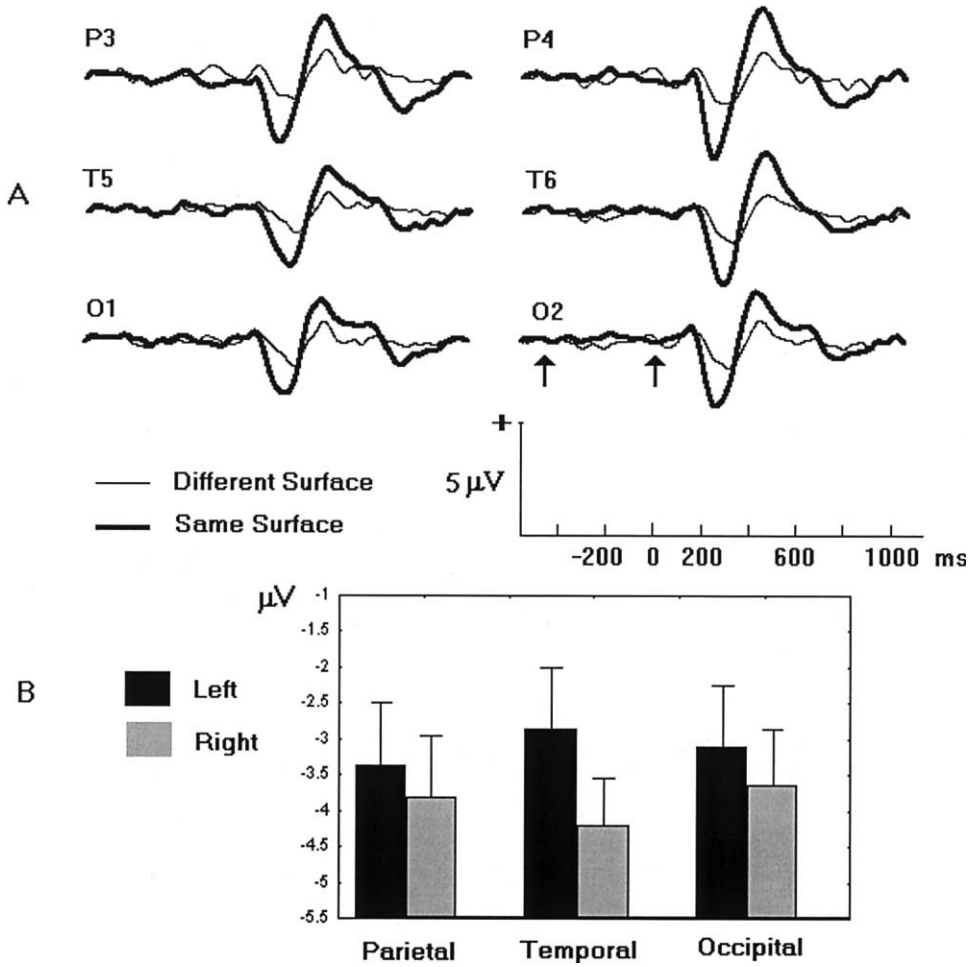

Fig. 4. (A) Grand average difference waveforms from Experiment 2, with the isolated response to the second event. Responses to same- (cued) and different- (uncued) surface trials are overlaid. The time axis is referred to the onset of the second event. Positive points up. The two arrows indicate times when events were presented. (B) Average amplitude (with baseline corrected) of N1 as a function of site (same locations as in A) and side of the scalp. The measure was obtained for the same-surface condition and for the time window defined in the text. Each data point corresponds to the mean of 10 subjects. The whiskers represent 1 S.E.

In the rm-ANOVA on N1 amplitudes from all sites, number-of-surfaces, $F(1,9) = 4.8$, $P < 0.06$ was marginally significant, and electrode, $F(7,63) = 4.2$, $P < 0.009$, $\varepsilon = 0.3$, and the interaction of the two factors, $F(7,63) = 4.5$, $P < 0.004$, $\varepsilon = 0.26$, were significant. However, after normalizing the amplitude measurements as recommended by McCarthy and Wood (1985) for testing with ANOVAs effects on the scalp topography of ERP components, the interaction of number-of-surfaces with site was not significant, $F(7,63) = 1.1$, $P > 0.3$, $\varepsilon = 0.4$. This indicates that the amplitude change of N1 as a function of attention was not associated with a change either in scalp topography or in latency.

In order confirm the results just described and to better determine the onset latency of the attentional effect, the ERPs associated with same- and different-surface trials were compared with t-tests (corrected by the use of permutation techniques at each time point. The two ERPs were different in the global test, $P < 0.02$. The earliest difference between conditions was detected at the T6 electrode site, at a latency of 171 ms after the second event with a $P < 0.036$. The effect in that site was significant at the 0.001 level from 190 to 277 ms, and the last significant point was at 280 ms, at the 0.05 level. These time limits overlap with those of the N1 component.

Table 3
Mean and S.D. of the ERP peak latencies across participants in Experiment 2 in the difference waveform that isolates the response to the second event[a]

	P1	N1
Mean	130	262
S.D.	40	33

[a] Each estimate is based on 10 participants and measured at T6.

Summarizing, when the subjects had previously engaged their attention on a surface, the N1 elicited by an event on that surface was significantly larger than when the event affected the other surface. The variation of N1 associated with attention did not produce changes in the topography of the component, nor important changes in its latency. The relatively early latency of this effect and the absence of topographic changes differentiate it from attentional selection negativities described by previous reports (Anllo-Vento & Hillyard, 1996).

The N1 attentional effect described here is similar to that found for the N1 elicited by sudden-onset stimuli in spatial cueing tasks (Mangun & Hillyard, 1991; Eimer, 1993, 1994a; Luck et al., 1994). This type of effect has been considered to be a hallmark of spatial attention. In agreement with our previous reports (Valdes-Sosa et al., 1998; Torriente et al., 1999), the present experiment shows that motion-onset ERPs can also be modulated by object-based attention in the absence of spatial displacements of the focus of attention. However, the N1 described here is of longer latency (260 ms) than what is typical of the N1 elicited by sudden-onset stimuli which is about 180 ms. This may create some doubts on how to interpret the result, and this problem is addressed in the next experiment.

4. Experiment 3

The N1 elicited by events in Experiment 2 peaked about 80 ms later (at 260 ms) than what is typical for the N1 in studies of visuo-spatial attention, or in the study of the AB by Vogel et al. (1998). The N1 elicited by sudden-onset patterns in studies of spatial attention ranges in post-stimulus latency from about 150 to 200 ms (for a review see Näätänen, 1992). At first glance, this seems to indicate a later locus for attentional influence during the SurfDT than for spatial selection. However, the latency of any ERP component is influenced by many stimulus factors such as the luminance or contrast. Here we examine one stimulus factor that can influence the latency of the motion-onset ERP, adaptation to a previous period of motion.

The N1 elicited by the motion-onset of previously stationary patterns usually has a shorter latency, at about 180 ms (Göpfert et al., 1990; Kuba & Kubová, 1992a; Kuba & Kubová, 1992b; Bach & Ullrich, 1994; Torriente et al., 1999). However, the events in the present study were presented after a period of background rotational motion. A recent study shows that the amplitude and latency of the N1 elicited by motion-onset are respectively reduced and delayed after pre-adaptation by a previous period of motion stimulation (Muller, Göpfert, Breuer, & Greenlee, 1998–1999). Therefore, the latency values of N1 here may reflect sub-optimal stimulation conditions related to this motion pre-adaptation.

4.1. Methods

The method was the same as in Experiment 2, except as described in the following. Only five subjects were recorded. Only single event trials were used (Fig. 1). Events lasted 100 ms. The speed of the baseline rotational motion was randomly selected among four alternatives: 0, 20, 40 and 80°/s of rotation for each trial. This corresponds to a stationary background, and to rotational motions that were half, the same, and twice as fast as the rotation in Experiment 2. A total of 120 trials were presented using each background speed. The ERPs elicited in trials with these different background speeds were averaged separately.

4.2. Results and discussion

The latency of N1 was shortest when the background was stationary and increased monotonically as the speed of the background rotation was increased. This can be observed in the grand average ERPs (Fig. 5A) recorded at electrode sites T6, and the plot of the corresponding mean peak latency of N1 for each condition at T5 and T6 (Fig. 5B). The effect of background speed was significant in a rm-ANOVA including the measures in Fig. 5, $F(3,12) = 22.6$, $P < 0.001$, $\varepsilon = 0.6$. The effect and interaction involving electrode site (T5 vs. T6) were not significant. A contrast analysis showed a significant linear trend, $F(1,4) = 45.0$, $P < 0.003$. The shift in latency as a function of background speeds ranged over 60 ms and for the speed used in Experiment 2 the latency shift respect to the stationary background would have been about 41 ms at T6.

These results indicate that the relatively long N1 latency found in Experiment 2 can be explained in part by the effect of a moving background period. In fact, this latency shift could correspond to visual motion adaptation. The magnitude of the adaptation effect was probably underestimated in the present experiment, since only the first events were presented after 800 ms of baseline rotation, whereas the second events in Experiment 2 were presented after 1250 ms of motion (Fig. 1). The implication of these findings is that the N1 that is modulated by attention in the present study corresponds to a component that under optimal stimulation conditions would typically have a latency of about 190 ms.

5. General discussion

In Experiment 1, large reductions of the sensitivity for detection of an event affecting an unattended sur-

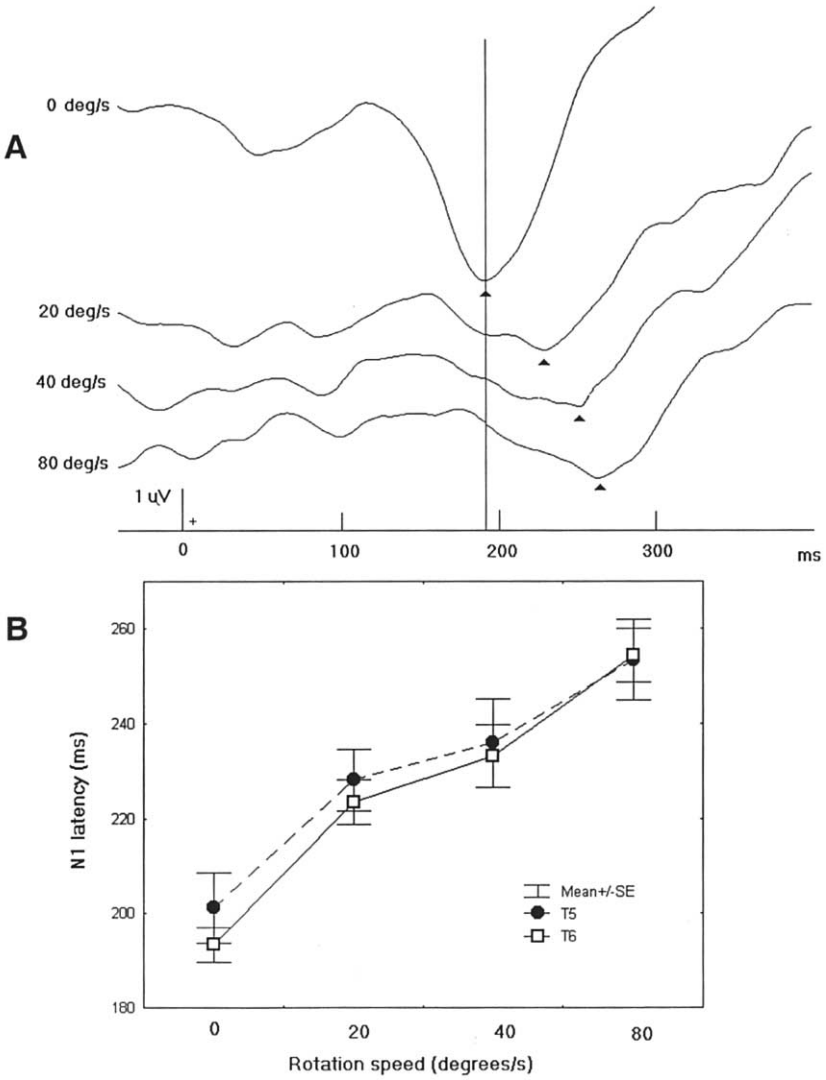

Fig. 5. (A) Grand average ERPs from T6 in Experiment 3. Each row corresponds to a different background speed of rotation. The arrows indicate the N1 peak latency. The amplitude decreases and the latency increases for larger rotation speeds. (B) The mean peak latency measured at T5 and T6. Each data point corresponds to the mean of five subjects. The whiskers represent 1 S.E.

face were found relative to detection of events affecting the attended surface. This demonstrates that SurfDT hampers both discrimination and detection of events. In Experiment 2, the N1 elicited by the second events were reduced in amplitude during the different-surface trials as compared with the same-surface trials. Suppression was already significant as early as 170 ms after the event. The third experiment suggests that N1 latency here was prolonged due to motion adaptation, and that this latency with a stationary background would be at least 40 ms shorter.

As mentioned before d' is considered to reflect perceptual processes, uncontaminated by guessing, or output biases. Therefore, the reduced d' associated with SurfDT is not explainable by changes in the subject's response criterion, or guessing strategies. The fact that SurfDT is related to both discrimination and detection deficits is another point of similarity to the AB in addition to its long temporal course (both near 500 ms).

Our previous study (Valdes-Sosa et al., 1998) evinced a strong suppression of both the P1 and N1 for events affecting the unattended surface, when the perceptual load was very high (fast event presentation rate) and attention was sustained on one surface for several minutes. In the present study we show that the relative suppression of N1 is also related to the sluggish shift of attention from one surface to the other within the same trial, providing converging evidence for early selection in the SurfDT.

This result is also in line with the spatial cueing ERP studies, where larger sensory-evoked responses are observed for targets on validly cued positions than on invalid ones, reflecting an enhancement of sensory processing. However, there is one interesting discrepancy.

In trial-by-trial spatial cueing tasks, when both validly and invalidly cued stimuli required a response, the early ERP modulations are smaller than when responses are only required for the valid stimuli (Eimer, 1994b). This indicates that asking for responses to invalidly cued stimuli favours attentional reallocation (perhaps by faster shifts of attention) within a trial.

Here, subjects were asked to respond to events affecting both the attended and unattended surface. Despite this, modulation of early components is obtained. Also in a previous study (Cobo, Pinilla, & Valdes-Sosa, 1999) found that the duration of SurfDT was unaffected even when subjects had foreknowledge about the need and the direction of an attentional shift (e.g. from red to green or vice versa). This indicates that suppression due to SurfDT is possibly stronger than in spatial cueing tasks and less subject to strategic control. The superposition of the two surfaces in transparent motion may have to do with this finding. A recent model has argued that one of the functions of attention is to reduce ambiguity within receptive fields (Luck, Girelli, McDermott, & Ford, 1997). In transparent motion, the degree of ambiguity to reduce may be larger than in spatial cueing experiments.

The finding of a N1 modulation associated with SurfDT indicates a difference of this phenomenon from the AB. In a previous study (Vogel et al., 1998) the AB is not associated with variations of P1 or N1 amplitudes, therefore concluding that the AB reflects a relatively late suppression of information. In that case the AB and SurfDT could arise at different processing stages. Nevertheless before accepting this conclusion, a potential problem with the irrelevant-event technique used in the mentioned study must be considered.

ERPs recording in RSVP is complicated by the overlap of signals caused by the fast-paced successive stimuli. To solve this problem for the study of the AB, Vogel et al. (1998) introduced one irrelevant-event on certain runs of RSVP at a certain temporal position that varied over runs. The irrelevant-events were bright squares flashed behind the second target. Subtraction of the ERPs associated to runs without events from runs with events should isolate the response triggered by the event. The rationale is that the amplitude of the P1 and N1 should reflect attentional modulations within the visual system as a function of time. They found that despite substantial impairment of accuracy in discriminating the T2 at certain times within the RSVP run, there was no suppression of the P1 and N1 elicited by the corresponding irrelevant-events compared to events presented at times with no interference.

A relatively salient event (pattern-onset and luminance-increment), is capable of attracting attention automatically (Yantis & Jonides, 1990). The event may be irrelevant but it is not unobtrusive. An automatic attentional-capture by the probe could mask effects of the AB on the ERPs. The motion events used in our study do not capture attention to the same degree as sudden-onset stimuli (Yantis & Hillstrom, 1994). Further studies of the AB with the irrelevant probe technique are necessary, but with probes that are milder attention-grabbers. If the distinction between the AB and SurfDT is maintained, then we would have two paradigms that evince different mechanisms of selective attention. This opens the possibility that attention can 'blink' in different ways.

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